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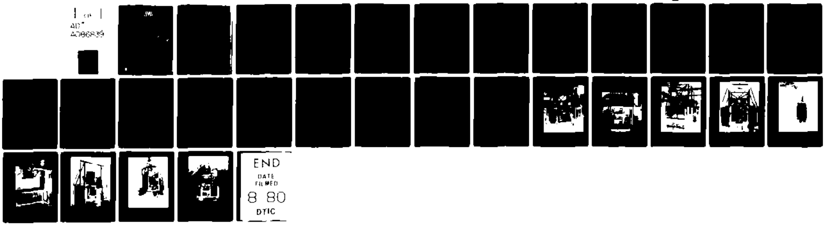

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LEVEL II

PAYLOADS USED IN FIRST THREE DATA-GATHERING BAMM FLIGHTS

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Payloads were configured for, and used in, three successful data-gathering balloon flights for the Balloon Altitude Mosaic Measurements (BAMM) program. All were significantly different, and each worked as planned. A radiometer and a TV camera were carried on Flight 1, and an interferometer was added for Flights 2 and 3. Recovery was by ground impact for the first two flights, but the third was snatched from the air by helicopter.

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PAYLOADS USED IN FIRST THREE DATA-GATHERING BAMM FLIGHTS

1. INTRODUCTION

When this contract began in November 1976 the Balloon Altitude Mosaic Measurements program known as BAMM had already started, and by mid 1978 had produced innumerable special elements necessary for carrying through the complicated program. These included plans for launching at several sites, with air recovery of the payload; mostly new and very special ground support facilities for data handling, payload control, tracking, and TV monitoring; two types of sophisticated sensing instruments; and a payload designed to keep the instruments pointed with great precision at command-selected ground targets even though the balloon was traveling at speeds up to 30 knots.

First attempted use of that system was made on 6 April 1978 in a balloon launch from Holloman Air Force Base. The gondola was badly damaged at the time of release, but fortunately the critical instruments were not lost. Need for extensive repair as well as major redesign meant the opportunity to collect data in the spring of 1978 had been missed, and there was little hope that the system could be ready for reuse by fall when the winds aloft would again be below 30 knots.

There were two problems with the original BAMM payload; a structural weakness had to be corrected, and the system was too heavy for air snatch. The latter problem was studied here, and a plan was developed whereby the catch weight could be reduced to acceptable limits by transferring some of the weight to a saddle-type load bar that would not be involved in the air snatch. A model was built at Tufts to demonstrate the plan, but no work was done to implement this design. Instead, the idea of dividing the payload into two parts was pursued by the group that built the payload, this work being done concurrently with redesign of the structure to make it worthy for balloon use. By early May it was evident that the rebuilt payload would not be ready for test until the spring of 1979.

In the hope that some data might be produced at an earlier time, Tufts was asked to consider putting together an elementary system to be used in a data-gathering flight at the time of the wind reversal in September. What was wanted was a simplified payload that could carry one of the two available sensing instruments, namely the radiometer, and would carry as well the essential companion facilities, including electronics for the sensing instrument, the TV camera, telemetry equipment, command equipment, and the electronics needed for flight control of the balloon. Pointing capability was not expected to approximate that of the original BAMM payload. Need for producing data in the BAMM program was such that any reasonable payload stability was considered acceptable.

What appeared to be achievable was a simple altitude-azimuth control that would hold the azimuth heading to a fraction of a degree, possibly $\pm$ 1/4, and would hold the elevation heading with similar or better precision. There would be no facility for changing heading angles continuously to compensate for balloon movement. Such a limited system could produce very useful data on a day when the wind speed aloft is very low, a situation that does occur just at the time of wind reversal.

Important equipment available at Tufts included a gondola framework that lacked many of the features needed for this application, a good gyrocompass which could serve as an azimuth reference, and a powered rotator that could be placed in the suspension system and used to rotate the entire payload in azimuth, but none of the electronics needed for azimuth stabilization was available. A gimbal arrangement within the gondola was movable about an elevation axis, but there was no mechanism available for driving it. The gondola did include four hoppers, without control valves, and two thermally insulated packages where instrumentation could be located. It was an assembly of spare parts that had been produced for refurbishing a 24-inch balloon-borne telescope system that was flown on a number of occasions during the 1960's. As originally used in that system, the entire gondola was roughly oriented in azimuth by means of the powered rotator, and fine pointing was accomplished by moving the inner assembly about an elevation axis and a cross-elevation axis, the control signals for these axes coming from star trackers. The cross-elevation axis was useless for BAMM because no suitable error signal for controlling it was available. Also, more space was required to carry the radiometer, its electronics, and the TV, then was available on the cross-elevation platform.

Possibilities for contriving a gondola that could be flown in September were studied during the last two weeks in May. It was appreciated from the beginning that a demanding work schedule would be necessary if shipping and preflight checkout was to be accomplished by mid-September, the target readiness date.

2. FIRST BAMM FLIGHT

2.1 Preparations

Getting ready for the first BAMM flight involved solving a good many problems in a short time, this by a very small group. Trials and tribulations were inevitable. What follows is a brief outline of the work that had to be done, which involved converting the skeleton framework available at Tufts to a working gondola.

Four problem areas had to be dealt with, namely to revise the basic structure so that it would carry all of the necessary peripheral equipment, to reconfigure the inner assembly for proper mounting of the experiment, to provide commandable controls for the elevation and azimuth axes, the latter to be servo controlled, and to plan and wire the entire assembly so that all essential interfaces were accomplished.

It was evident at the start that some equipment items could be fitted into the existing thermally-insulated packages, and that some of them were too large to fit. Solving the size problem required that one side of the gondola be modified to hold a larger thermally-insulated package, and that the needed larger package be built. Racks to fit within the packages and hold the individual units also had to be made. A new base for the gondola structure was needed because the existing one obscured the view of the radiometer when it looked straight down. Opening the base weakened the structure so it was necessary to devise re-enforcements to preserve the structural integrity of the gondola. Other gondola problems concerned the need for a gimbal lock to safely hold the gimbal during parachute opening and recovery, and ballast valves for the four hoppers. Another modification involved adding three large heat sink surfaces in the upper part of the framework for mounting transmitters. Impact pads were also needed to absorb the expected shock at ground impact, and a special chute rigging was needed to make the parachute serve as a torsional connection between the balloon and the payload, this being essential for azimuth stabilization.

Reconfiguring the inner assembly involved a number of changes. The cross-elevation platform was removed and the elevation gimbal was rebuilt as a platform large enough to hold the television camera, the radiometer, and the two sizable electronic packages associated with the radiometer. Field-of-view considerations made it necessary to mount the television camera and the radiometer on the upper surface of the elevation platform, and special wiring requirements made it necessary to mount the two electronic packages there too; this introduced a large unbalance which had to be compensated by adding a weight-holding assembly on the opposite side of the elevation axis. Reconfiguring the inner assembly was problem enough, but a larger and more troublesome difficulty was imposed by the radiometer. Actually there were three problems: the existing mounting bracket was on the side of the radiometer instead of the bottom, and could not be shifted; it must be possible to remove and replace the radiometer without disturbing the system's optical alignment; and the filling ports were on the bottom of the unit, directly over the platform surface. The first two difficulties were eliminated by constructing a cradle that precisely fitted around the unit, with provision for easy removal and exact mechanical replacement, and the third was avoided by cutting suitable access holes in both the mounting cradle and the platform surface. There were no special problems associated with mounting of the TV camera, or the two electronics packages which had to be kept near the radiometer.

Electronics needed for azimuth stabilization had to be designed and built. Also needed was a provision for making commandable changes in the azimuth heading at either of two rates, and in either direction. This required that a special mechanical unit be designed and built. Although no stabilization circuitry was needed for the elevation axis, a drive mechanism was essential that could be commanded at either of two speeds. Implementation was achieved by a precision gear box linked to the elevation axis by means of a chain drive, backlash being avoided by a small unbalance about the elevation axis.

A final problem area was concerned with designing and making the cabling required to interconnect the equipment items. Some of these were located in the thermally-insulated packages, some were located on the elevation platform, some were located on the heat sink surfaces, some were antennas at the bottom of the payload, and of course some were as far away as the valve at the top of the balloon. Planning the interfacing was the work of all of the participating contractor and USAF groups, and the associated wiring was shared among the same groups. Scheduling the multiperson operation was successfully worked out even though it had to be done late in August and early in September, just before preliminary checkout operations were started.

Ninety-eight days after the frantic design and building effort began, the payload was shipped by van to Holloman on 8 September. Some preliminary system checkout and interference testing had been done, so the system was known to be functional, but the bulk of it had to be completed in the field. Intensive effort by all groups did produce a fully tuned and checked out payload just before the winds aloft "turnaround" arrived. The payload was a clean assembly that by any reasonable standards would be judged worthy for balloon use. Indeed, visitors from SAMSO, the agency that sponsored BAMM, made a field visit to verify that it was suitable for carrying the valuable radiometer instrument, and they judged it to be flightworthy.

2.2 Balloon Flight

After overcoming the innumerable obstacles encountered in preparing the system, and coping with the poor weather that preceded the flight, the payload was successfully launched on 28 September 1978. System performance was excellent throughout the ascent interval and throughout the data-taking period. Subsequently, while the balloon was being repositioned for recovery, the azimuth stabilization system ceased to function properly because of overheating, but by then the experiment was completed. Termination and descent on the parachute were perfectly normal, but the impact was unique; the payload landed astride the center line on a paved highway, and stood upright. Shock was nicely absorbed by the impact pads so there was absolutely no damage to the payload. Air Force recovery personnel reached the scene moments after the impact, being only a block away when touchdown occurred. A brief time thereafter the chase helicopter landed nearby, and that group joined the recovery party to take charge and get the payload off the highway. Subsequently other groups came to lend a hand in getting the equipment loaded and transported back to the launch site.

An enormous amount of high-quality data was obtained in this audacious experiment, made four months and twelve days after it was first suggested that a substitute gondola be used in the BAMM program. Accomplishing the building and preparation chores within the inflexible schedule was a tremendous achievement by groups of people who had not worked together previously.

2.3 Photographs of Payload for Flight 1

The photographs in Figs. 1 through 5 show some features of the gondola design. Fig. 1 is a view of the rack structure with the elevation platform tilted downward. Mounted on the platform are the TV camera, the cradle for the radiometer, and one of the electronics units. Heat sink surfaces used with two of the transmitters also can be seen in the photograph. Fig. 2 illustrates how the batteries and other electronic components were held in a thermally-insulated package. A similar view is shown in Fig. 3, in this case the thermally-insulated package is closed as it would be during flight. In Fig. 4 can be seen the completed payload arrangement, with the radiometer looking straight down. Shown in this view are the TV camera, the radiometer in its cradle, and the three electronics units that had to be adjacent to the radiometer and TV, and therefore had to be carried on the movable platform. Means used for re-enforcing the rack to compensate for the open base is evident. Finally, Fig. 5 is a view of the system immediately after its release from the crane that was used as a launch vehicle. Four impact pads needed to soften the landing, along with several antennas, are located at the bottom. Also visible is the lower end of the chute, which was rigged as a two-foot wide ribbon to serve as a torsional member between the payload and the balloon.

3. SECOND BAMM FLIGHT

3.1 Planning

Immediately after the successful data-gathering flight on 28 September, Tufts was asked to consider reconfiguring the gondola to carry both the radiometer that had been used on the first flight and an interferometer that was intended for use in the BAMM experiments. Limited space within the gondola, and the large size of the interferometer, plus additional electronics, command facilities, and telemetry needed for the interferometer, presented a near impossible task. Possibilities were researched throughout October and a fifth-scale model was constructed to demonstrate how the inner assembly could be rebuilt to accomplish the task. In this planning the cross-elevation axis feature was restored, which made it possible to use proportional controls on that axis and the elevation axis to continually change the heading to compensate for balloon movement. When the proposed solution was discussed at a BAMM planning meeting on the last day of October it was decided that the Tufts payload should be reconfigured for a data-gathering flight at the spring turnaround in May of 1979, and possibly in September when the winds aloft reverse direction again. Another feature of the plan was that the payload would be rigged either for air snatch or ground impact, the air-snatch feature being essential if the system was reflown in the fall at a coastal location.

Rebuilding the central portion of the gondola to incorporate the new facilities represented a very large effort which could barely be accomplished in the available time. The target date for transferring the rebuilt gondola to Bedford, where interfacing with other groups would be accomplished, including wiring, was 1 April 1979, which gave the small group at Tufts only five months to make a complete design and accomplish the manufacture. Interfacing and checkout at Bedford was to be completed by the end of April, at which time the near-ready system would be transported to Holloman AFB for a flight in May.

3.2 Preparations

First attention was given to the new inner assembly which would carry the TV, the radiometer, and the radiometer electronics, as was the case in the first flight, and carry as well the large and heavy interferometer and its electronics, along with a new drive mechanism for actuating the cross-elevation axis. To the extent possible, the components were arranged within the limited space in a manner that would produce approximate balance about both the elevation and the cross-elevation axis.

Particular attention was given to providing necessary access. There were no problems with the three electronic packages, but access to and removability of the radiometer and the interferometer presented real difficulties. The interferometer weighed 103 pounds, was extremely delicate, measured 30 x 18 x 11 inches, and had to be inserted into a space only slightly larger than the unit; this simply could not be accomplished by manual handling. Installation and removal was made easy by providing a removable monorail at the top of the rack with a small hand-operated hoist arranged to travel along the monorail. With this facility it was a simple matter to quickly lift the instrument from its confined space, then move the unit along the monorail to a clear space in front of the rack, and finally lower it to a padded portable table. A special mounting base was provided which allowed the heavy unit to be precisely put in place with assurance that the alignment of the instrument's optical axis with respect to the framework would be preserved. Positioning of the instrument was not adjustable, which meant the optical axis was fixed, the plan being to align the system by bringing the optical axes of the radiometer and TV into coincidence with the fixed axis. When the interferometer was in its confined space there was easy access to the filling ports, and adequate access to an area on one side of the instrument where optical adjustments could be made.

The cradle used for holding the radiometer for the first flight was used again, but it had to be extensively modified. Reason was that the interferometer was directly below the surface on which the radiometer was to be mounted, so there was no possibility of providing access for filling through a hole in the mounting surface as had been done previously. The problem was solved by enlarging the cradle that held the radiometer to include a precision hinge which would allow the entire assembly to be swung away from its flight position, thereby permitting access to the filling ports at the bottom of the unit. Provision was also made for conveniently aligning the radiometer's optical axis with that of the interferometer. Earlier features of the special cradle were preserved, namely the ability to easily remove the instrument for safe keeping, and later restore it without disturbing the system alignment.

A new mount was also designed and built for the TV camera. It too could be adjusted in either of two directions to permit the optical axis of the camera to be brought into coincidence with those of the two sensing instruments.

A second major problem area was to produce drive mechanisms for both the elevation and the cross-elevation axes. These were larger and more complicated than the elevation-drive used in Flight 1. In addition to having commandable movement at either of two speeds, the units had a servo-operated proportional drive, and means for measuring angles which were fed to the computer that generated rate information for the proportional drives. Designing and making these units was indeed a very large effort that was considerably plagued by slow delivery of essential components.

Although the gondola rack had been extended for Flight 1 to include larger units, some further modifications were needed for Flight 2. Additional structural elements were added because the weight of the central assembly had been increased, and new suspension cables of larger size were procured for the same reason. A convenient removable platform was devised to carry the 100-foot packed parachute that is used for air recovery, and the special explosive release hardware needed in rigging for air snatch was also produced. Changing from, or to, the air-recovery configuration could be done easily and rapidly. Other modifications to the gondola structure involved providing heat sink space for more transmitters than were used on Flight 1, and ventilating the gyrocompass that overheated at the end of that operation. Space allotment within the thermally-insulated packages was changed in considerable detail to accommodate a number of new items, including two additional sets of batteries for the interferometer.

A considerable amount of time was devoted to electronics. A calculator was needed to solve the trigonometric equations that relate azimuth heading, elevation angle, cross-elevation angle, wind velocity, and wind direction to produce rates of change for the elevation and cross-elevation axes, this information being inputs to the velocity servos in the respective gear drives. Computation was accomplished with analog modules to avoid problems that might occur if microprocessors were placed in close proximity to other digital circuitry, and there was the additional concern that signals from a microprocessor might add noise to the low-level signals coming from the sensing instruments. Also, a good amount of new electronic circuitry was needed for the twenty-four command channels associated with the Tufts equipment. In the earlier flight the command system had provided the needed circuit closures for controlling the gondola, but in Flight 2 it was necessary to generate the multiplicity of circuit closures from a digital data stream. A final problem of significant size involved planning for and completely rewiring the gondola. This work was shared among the participating groups, the work being done at Bedford during the interface period which began on 2 April when the payload was transferred to Bedford and ended on 25 April when it was shipped to Holloman AFB.

Although a determined effort was made to complete all of the problems within the available time frame, this was not possible. Essential work was done, but the computer circuitry needed to compensate for balloon movement was not finished by flight time. It was, however, possible to operate one axis, and this allowed the usefulness and workability of the arrangement to be demonstrated.

3.3 Balloon Flight

Air recovery was planned for this flight, and indeed the recovery helicopters were brought to Holloman where several days were spent doing practice docking with a dummy payload. During this period the gondola was rigged for air recovery. However, the late appearance of the turnaround, and the consequent delay in the flight schedule, caused the aircraft to return home. Of course the payload was then re-rigged for ground impact, which was the configuration actually used when the launch was made on 29 May 1979. Prior to the launch there was opportunity to rehearse and practice the launch procedures; this experience helped make the actual launch the fine success that it was.

Performance of the payload was excellent throughout the entire time that the balloon was aloft. It traveled west at modest speed and reached an area where recovery would be difficult by the time data-taking was completed. It was then brought down to a lower level where it encountered westerly winds that brought it back to a more suitable area, and termination was executed. Unlike Flight 1, which landed on a smooth level surface, Flight 2 impacted on a difficult hillside, landing very hard on one corner of the gondola while traveling toward the hill. As a result there was a fair amount of distortion and bending of the structure, but there was absolutely no damage to any of the vital components, either the sensing instruments on the central assembly or those located in the thermally-insulated packages.

Checkout of the guidance system after the payload returned showed the system to be operating properly. Although the rack was bent and batteries had spilled, the gondola and the equipment survived for further use.

Flight 2 proved to be an enormous undertaking that demanded unreasonable effort from a good many people, but the bottom line made it all worthwhile; an abundance of fine data from two types of sensing insturments was produced for the first time in the BAMM program.

3.4 Photographs of Payload for Flight 2

Figs 6 through 8 illustrate several features of the redesigned gondola. Fig. 6 is a view of the central assembly, in this case facing forward. The radiometer and TV camera are in place, and three of the electronics units can be seen, but the large space reserved for the interferometer is vacant. Means of installing the interferometer is shown in Fig. 7. Here the central assembly has been oriented with the radiometer looking downward, thereby permitting the large interferometer to be lowered into its proper place in the structure by means of the hand-operated hoist. The monorail on which the hoist travels can be seen at the top. A view of the completed assembly is shown in Fig. 8, with the instruments looking downward, and the chute taut as a result of the ongoing inflation. Impact pads are in place, and numerous antennas protrude from the base.

4. THIRD BAMM FLIGHT

4.1 Preparations

Preparations for BAMM Flight 3 involved fewer problems, but the time available from the start of work in early July to the transfer of the gondola to Bedford on 9 August was only five weeks. This gave plenty of time to clean up and repair the gondola before transfer to Bedford, and to integrate and check out the complete system prior to shipment on 14 September, provided no improvements were attempted. However, important changes were incorporated which made the schedule tight; the gear drives for the elevation and cross-elevation axes were modified, a gimbal lock was added, and the electronic circuitry needed to compensate for balloon motion was completed.

When the central assembly was rebuilt for BAMM Flight 2 the design of the gear boxes for the elevation and cross-elevation axes included large worm gears, a feature which made it unnecessary to lock the gimbal during launch and recovery as had been done in Flight 1. But friction in the worm gears considerably reduced the available torque at the output shaft, so for Flight 3 the worm gears were replaced with spur gears. Much more torque was available from the revised units, but the use of spur gears necessitated incorporating a gimbal lock to securely hold the inner assembly during the recovery operations. A new commandable locking mechanism had to be designed and built because the one used on Flight 1 was not suitable for the inner assembly used for BAMM Flights 2 and 3. Rebuilding the gear drives, and providing the gimbal-lock feature, represented more work than was required for repairing the gondola.

There was time available during the integration and checkout at Bedford to complete the compensation circuitry. This work had been partially done for Flight 2, but for Flight 3 the plan was fully implemented. Proportional drive features in both gear drives were operable, and the electronic calculator was completed. This circuitry solves the trigonometric equations that relate wind velocity, wind direction, azimuth angle, elevation angle, and cross-elevation angle to produce inputs to the proportional drives.

When the preparations for the third BAMM flight were completed, the gondola that had been conceived during October of the preceding year was finished in every detail, just eleven months after the concept was first presented, and BAMM Flight 2 had been made, with subsequent repair, all in the span of less than a year.

Air recovery was a necessity for the third BAMM flight because the launch was from Keesler AFB, right on the Gulf of Mexico. Accordingly the gondola was rigged to include the special packed chute arrangement that had been available for the second BAMM flight, but was not used on that occasion.

4.2 Balloon Flight

BAMM Flight 3 was launched on 8 October 1979. Everything relating to the launch and the flight was a fantastic success; all systems worked as planned, including a trajectory that permitted the areas of principal interest to be studied.

Recovery, which is always exciting, was particularly so in this instance because it was the first time a fully instrumented payload had been snatched from the air in the BAMM program. This fact will identify BAMM Flight 3, particularly since the catch was made on the first pass and the payload was delivered back to the designated area with great precision and gentleness. No shock forces whatever were involved as the gondola was lowered to the runway, without even damaging the impact pads.

4.3 Photograph of Payload for Flight 3

Fig. 9 shows the payload as it was rigged for Flight 3. Its outward appearance is identical with the arrangement used for Flight 2, with the single exception that the special chute needed for air recovery is mounted on a special grill at the top of the rack.

5. CONCLUSIONS

Stable platforms were built for three data-gathering balloon flights in the Balloon Altitude Mosaic Measurements, BAMM, program. Each of the three gondolas was significantly different, and each worked as planned. A radiometer and a TV camera were carried on the first flight, and an interferometer was added for the other two. Compensation for balloon movement was not attempted for Flight 1, it was included but only partially implemented for Flight 2, and it was completely operable for Flight 3. Air recovery of the payload was a part of BAMM Flight 3.

Payloads used in the BAMM flights were put together by Tufts on an emergency schedule to replace the one that had been designed for the program, and that had experienced a structural failure when first used. Pointing capability of the substitute gondolas was not intended to equal that of the one that failed. Time span, from the first discussion of a substitute payload to the completion of the third data-gathering flight, was 17 months, less 8 days. A great quantity of useful data was obtained in the three experiments, and at this point in time it represents the only data in the BAMM program.

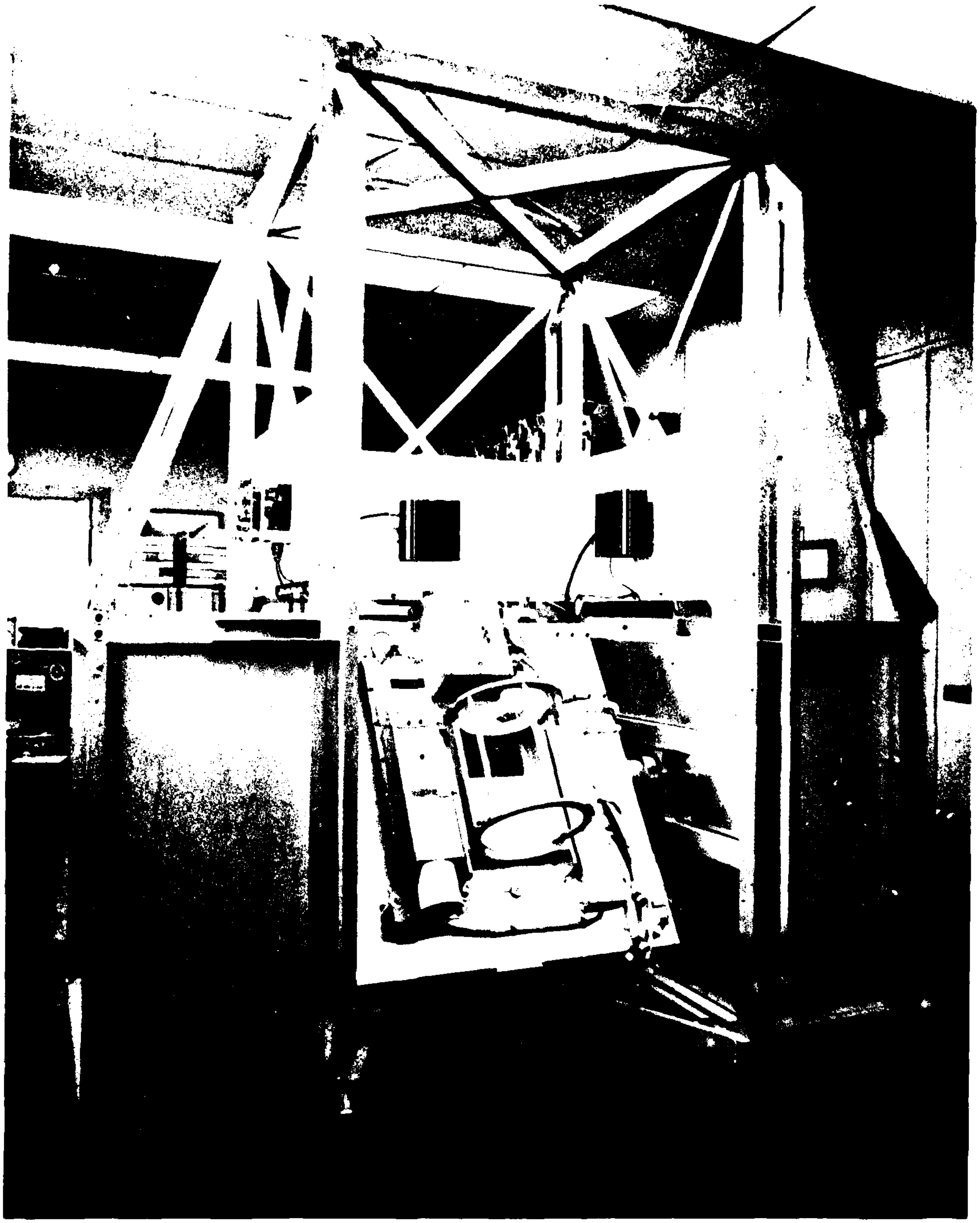

Figure 1. Rack Structure, Showing Tilted Elevation Platform, Including TV Camera, Electronics Package, and Radiometer Cradle

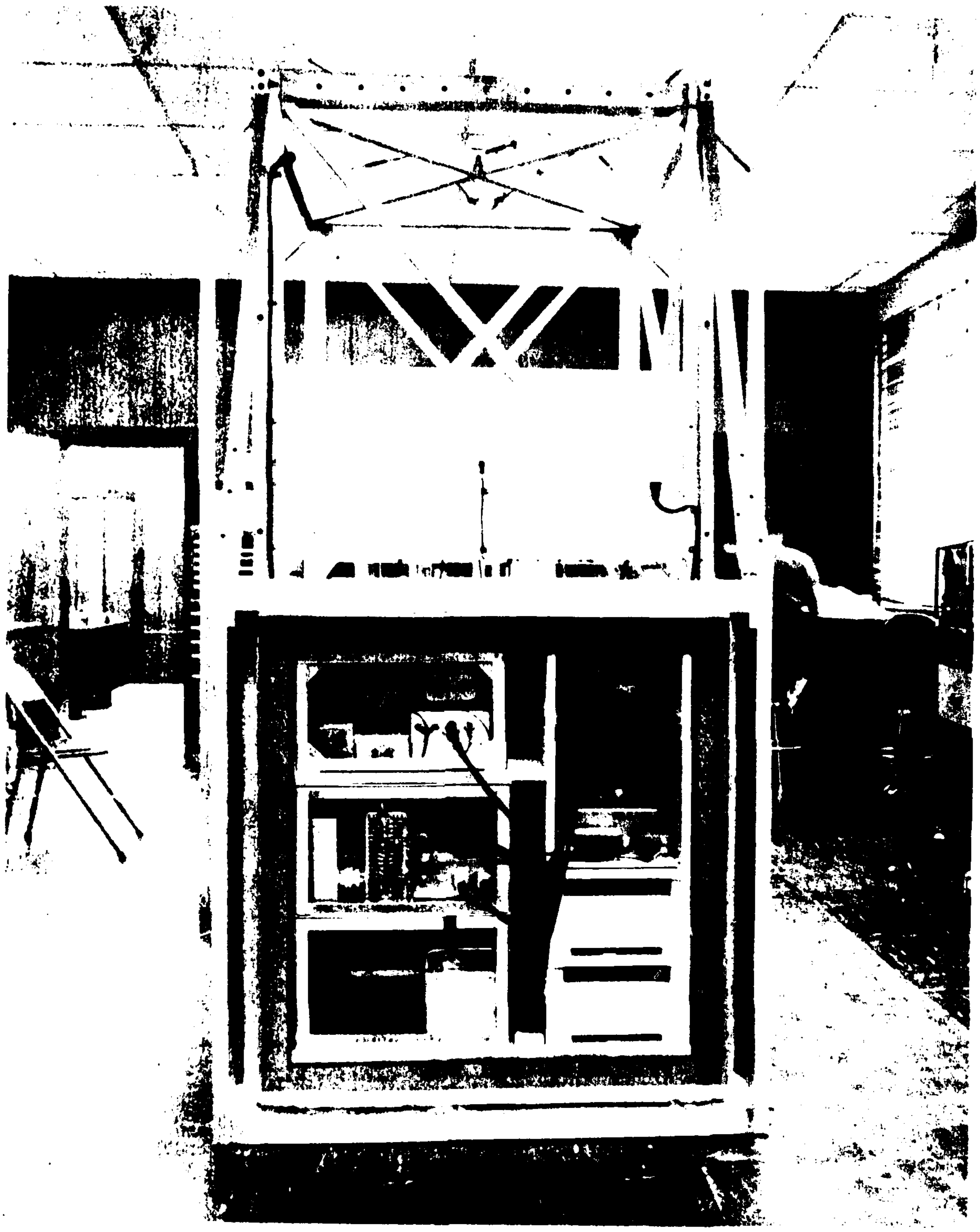

Figure 2. Mounting Arrangement Within One of the Thermally-Insulated Packages

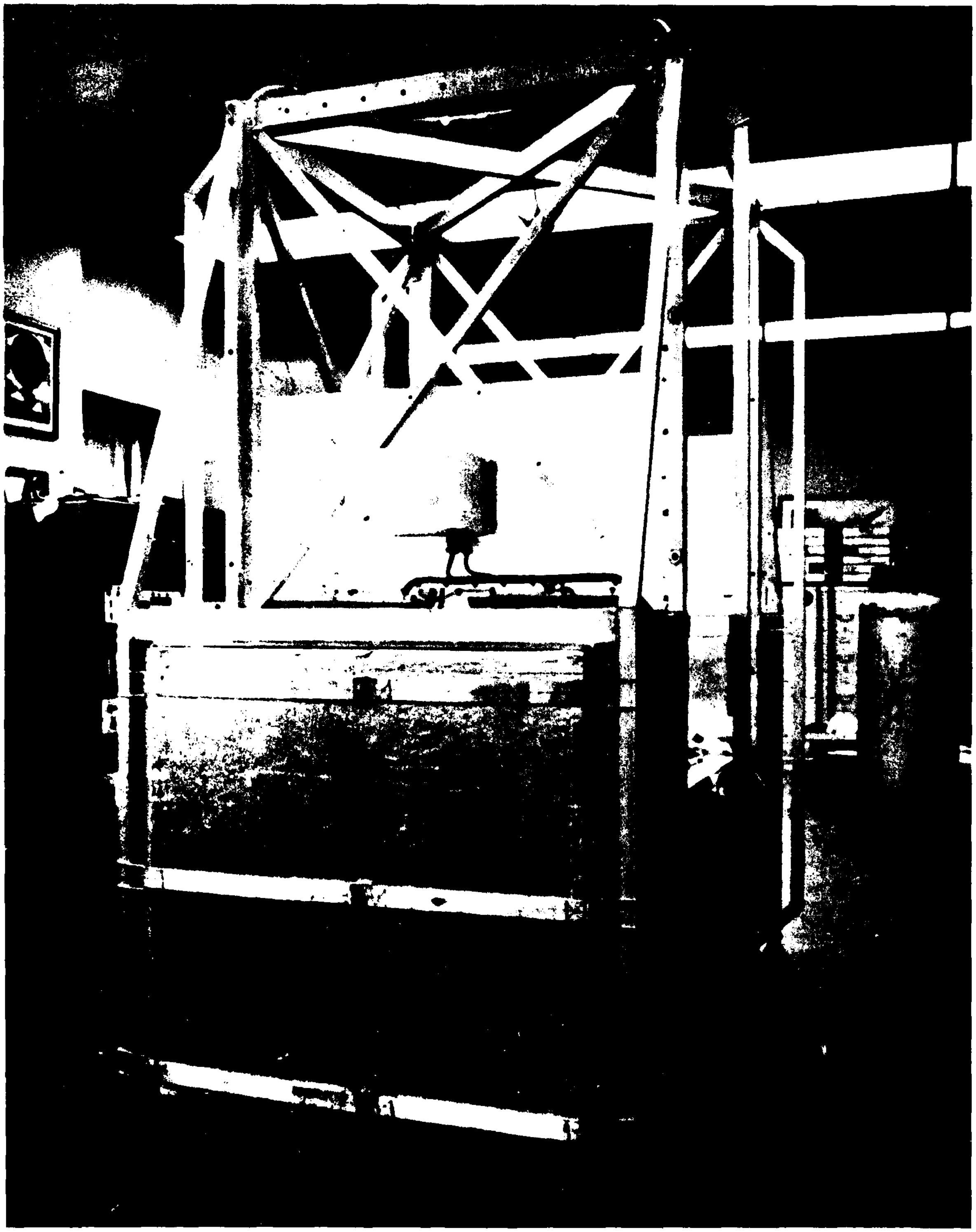

Figure 3. Partially Completed Gondola Showing How Thermally-Insulated Packages are Closed

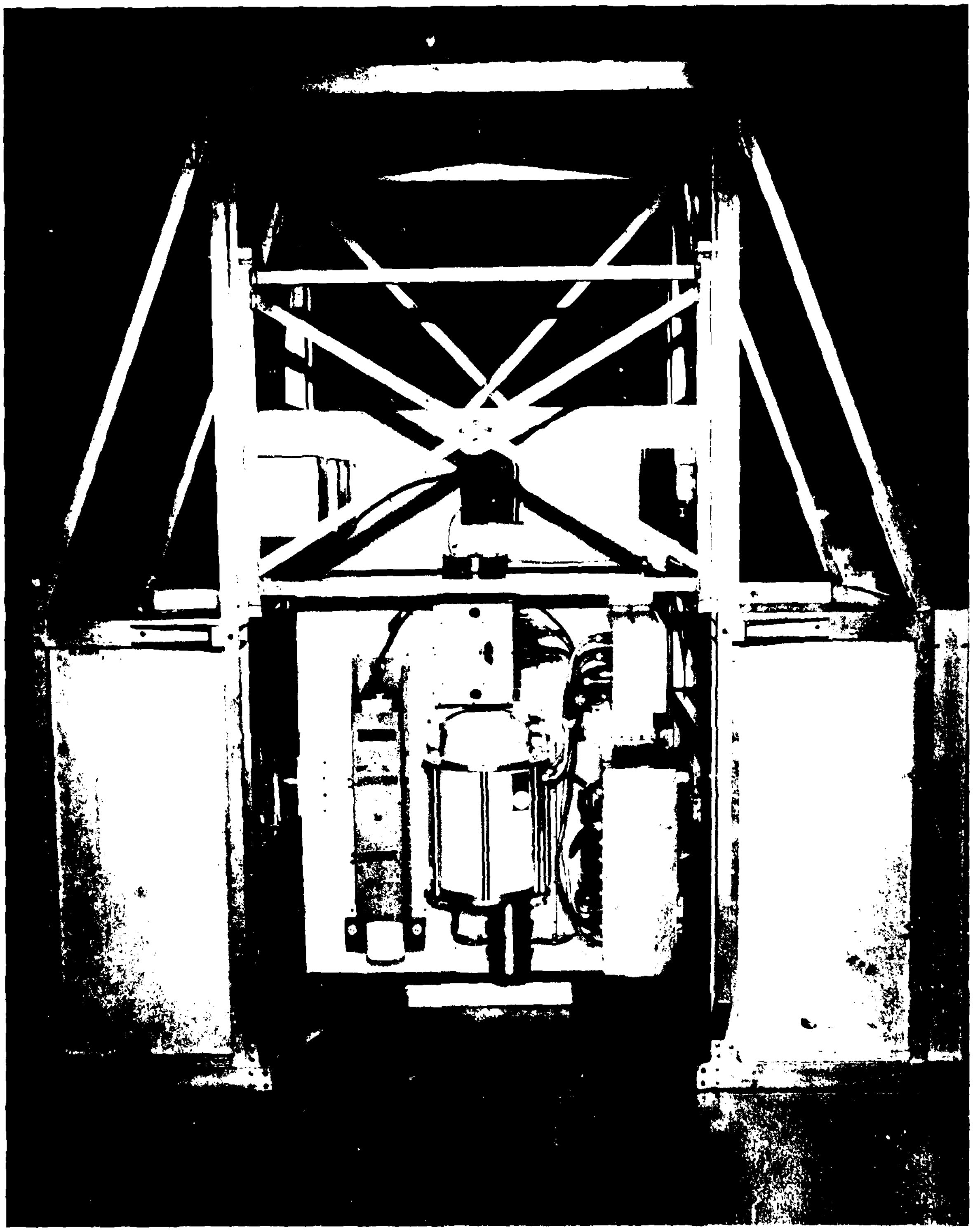

Figure 4. Fully Assembled Gondola with Components in Place, Including TV Camera, Radiometer, and Electronics Units

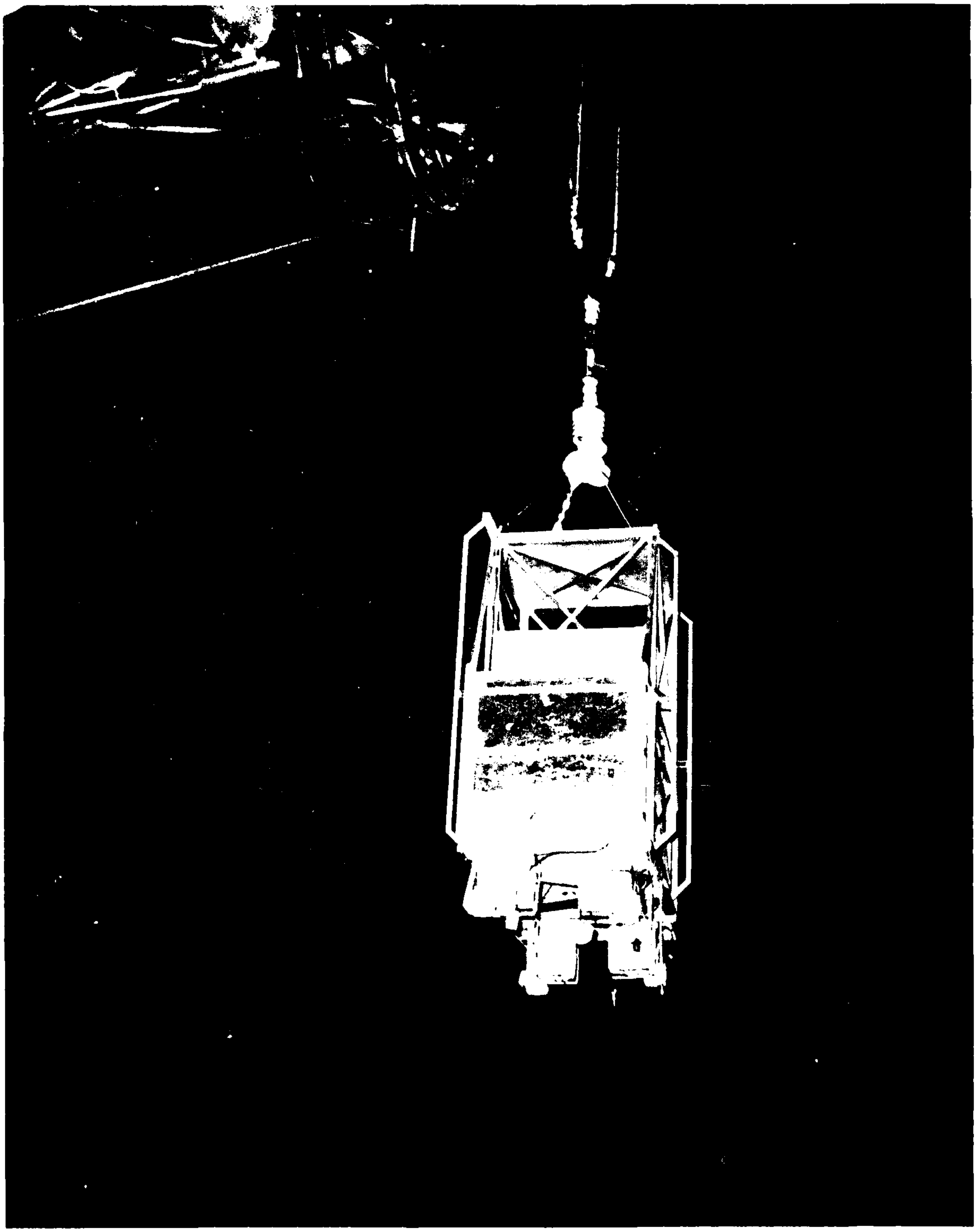

Figure 5. Gondola Moments After Release, Showing Impact Pads, Antennas, and Chute Rigging

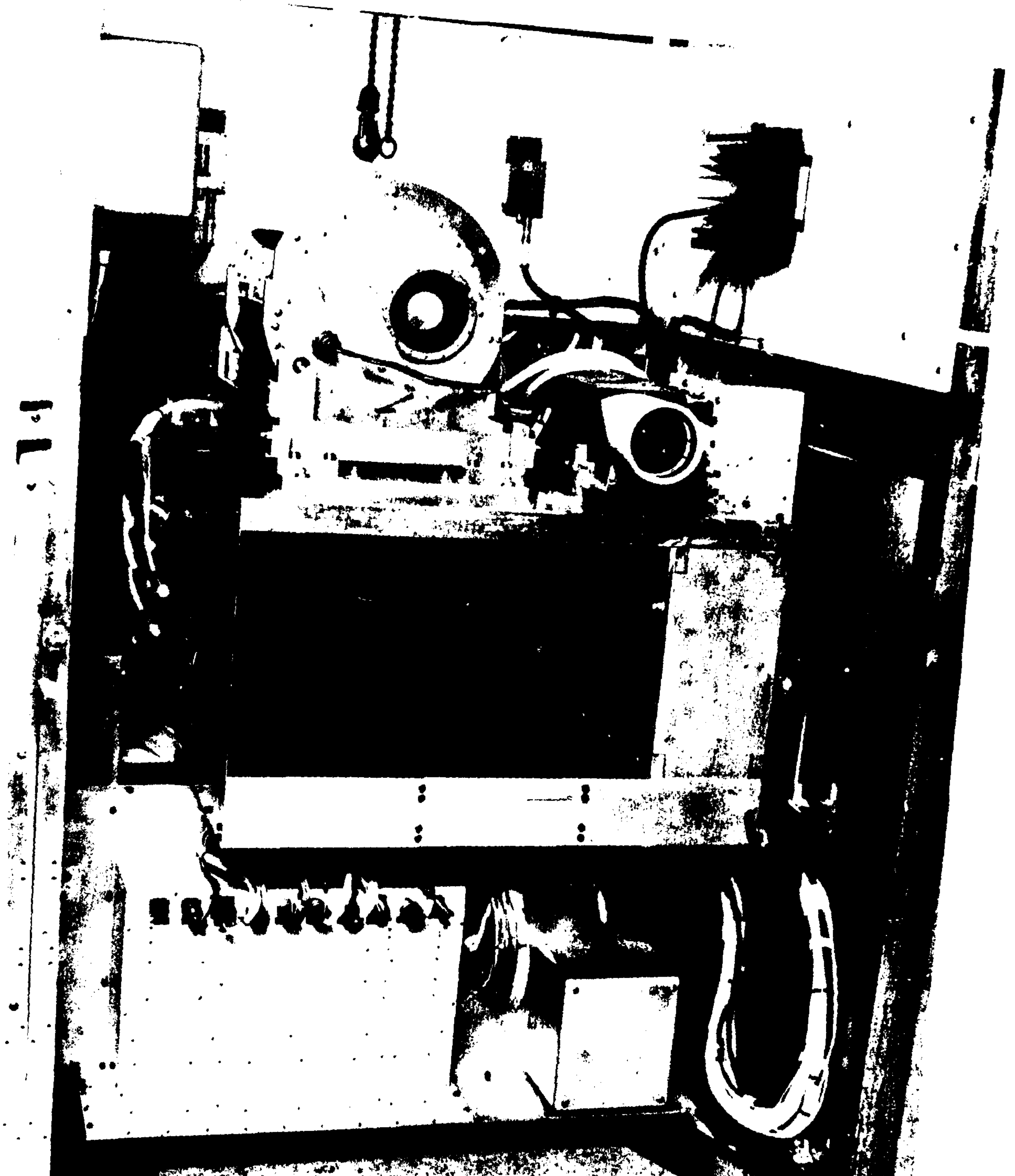

Figure 6. Central Assembly Showing Radiometer, TV Camera, a Few Electronics Units, and Space for Interferometer

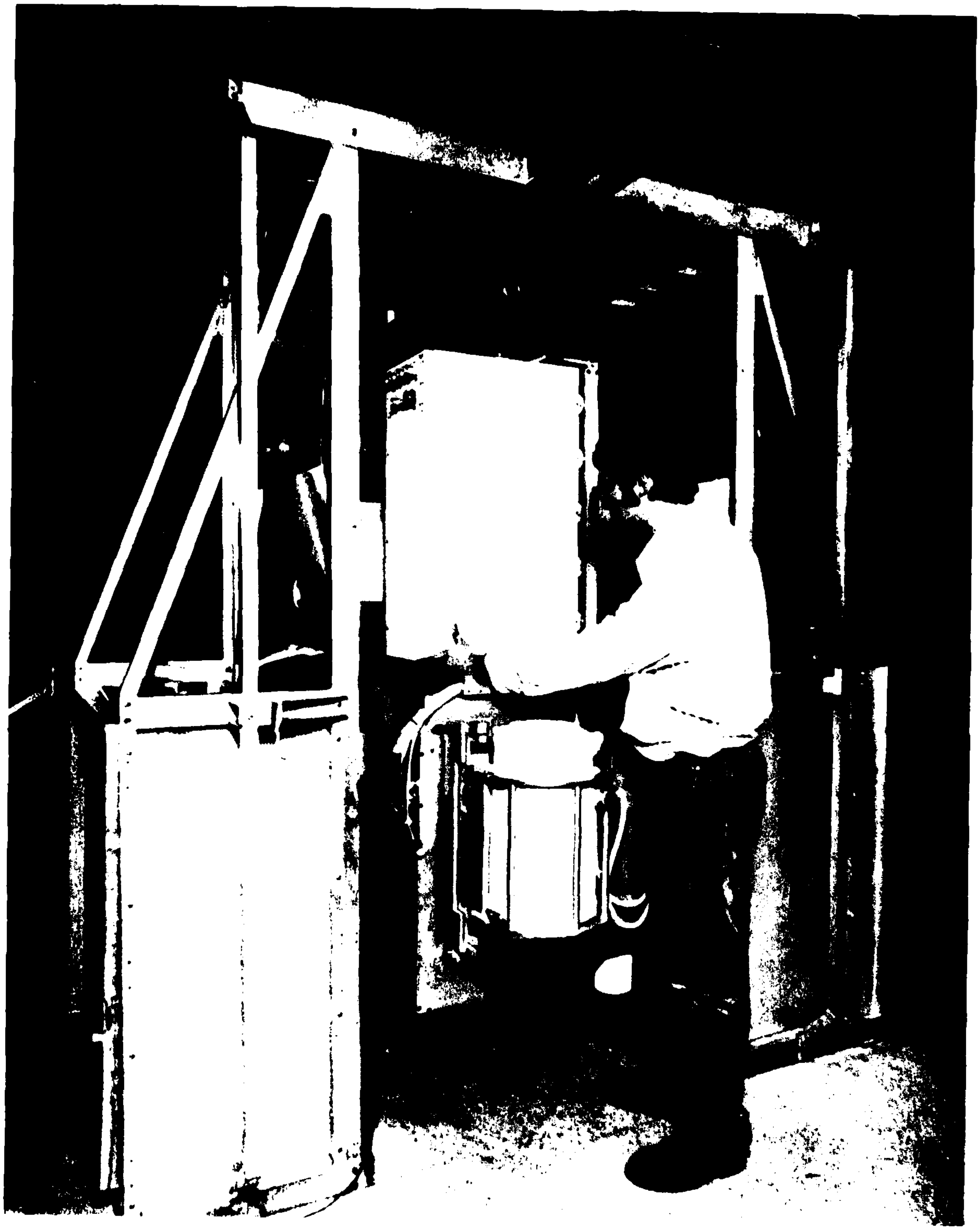

Figure 7. View Showing Interferometer Being Lowered Into Place, Using Hand-Operated Hoist That Travels on Monorail

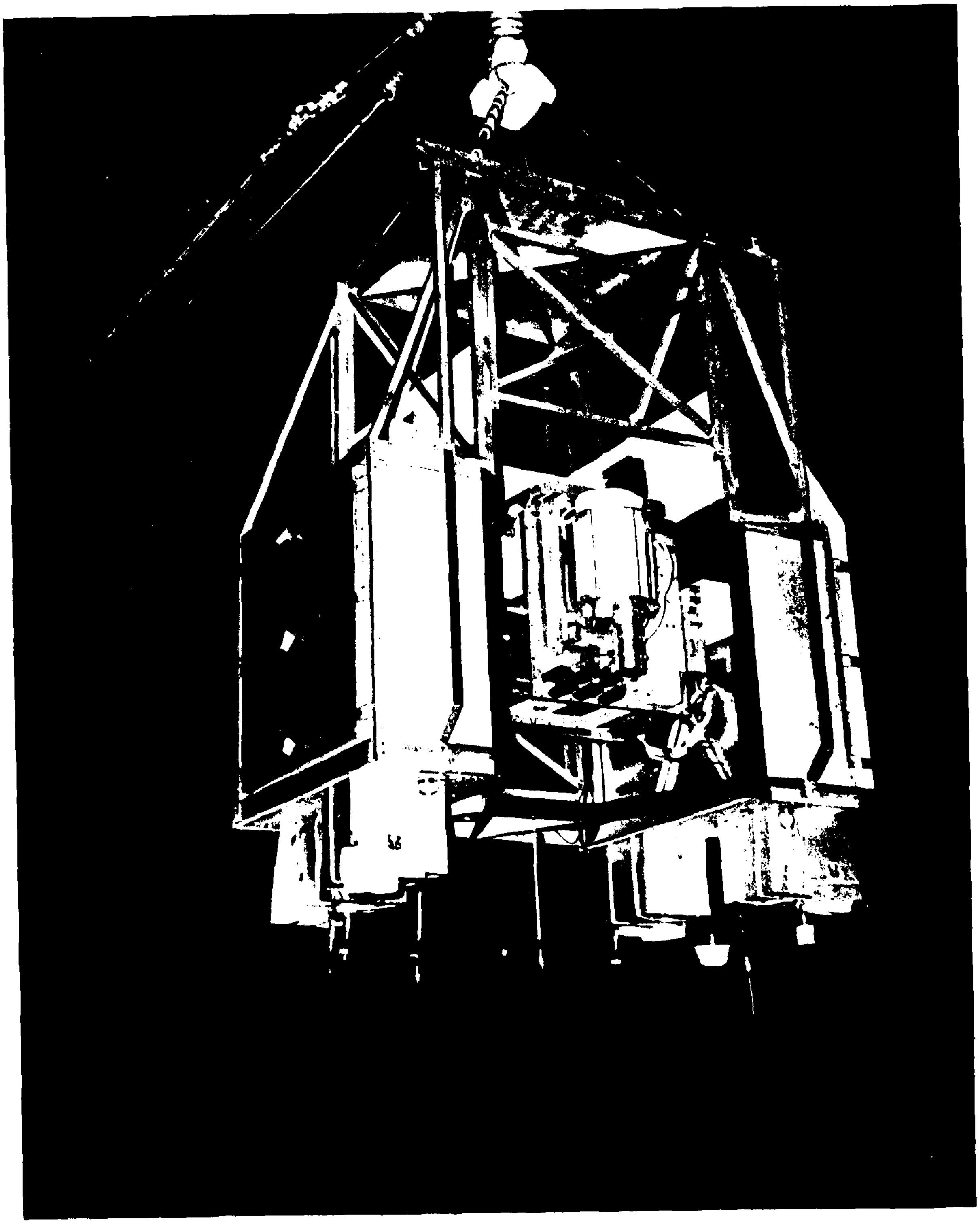

Figure 8. Fully Rigged Gondola During Inflation for Flight 2

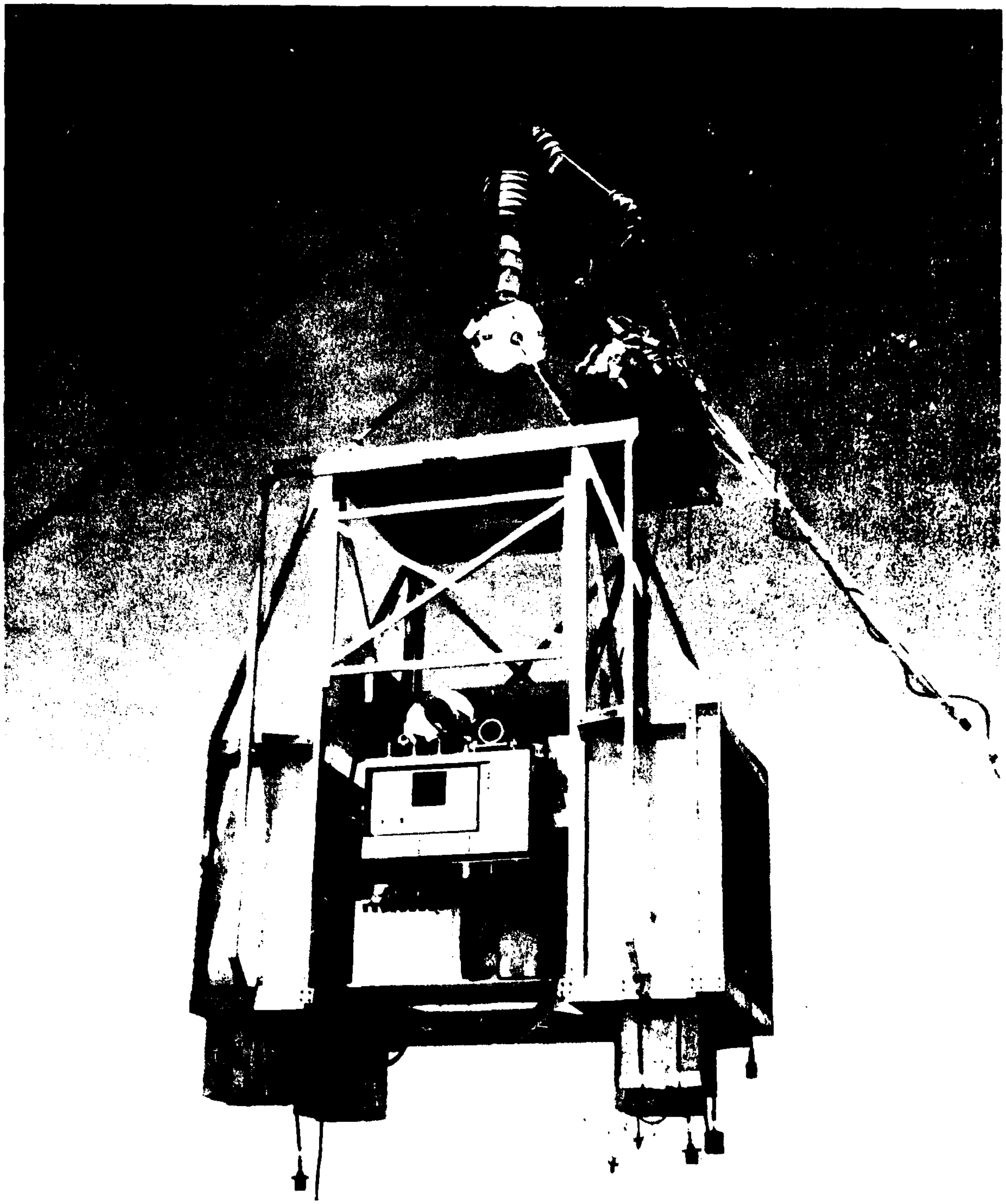

Figure 9. Payload as Used for Flight 3, Completely Rigged with Special Chute for Air Recovery